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THE APPLICATIONS OF SPACE TECHNOLOGY FOR INTEGRATED LAND AND WATER RESOURCES MANAGEMENT FOR RURAL DEVELOPMENT

Note by the Secretariat

1. The Working Group of the Whole to Evaluate the Implementation of the Recommendations of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 82), in the report on the work of its fifth session, proposed that a few specific space applications studies should be carried out to demonstrate the potentials of space technology. The Working Group identified a number of possible subjects for such studies, including the subject of integrated land and water resources management for rural development, and proposed that, as a first step, information on some of those subjects might be provided as part of the United Nations efforts in conjunction with International Space Year (A/AC.105/483, annex II, para. 6).

2. The Working Group noted that two such studies had been prepared by the Secretariat for the twenty-eighth session of the Scientific and Technical Subcommittee: a study on flood monitoring and control (A/AC.105/472) and a review of upper atmosphere studies for weather and environment monitoring (A/AC.105/477).

3. The report of the Working Group was adopted by the Scientific and Technical Subcommittee in its report on the work of its twenty-eighth session (A/AC.105/483, para. 22), and the recommendations were endorsed by the Committee on the Peaceful Uses of Outer Space in its report on the work of its thirty-fourth session 1/ and by the General Assembly in its resolution 46/45 of 9 December 1991.

4. The present study has been prepared by the Secretariat in response to the request of the Working Group of the Whole. Its purpose is to review the applications of space technology for integrated land and water resources

management for rural development. The study is intended primarily for the benefit of countries that have not yet used space technology for this purpose but are interested in its potential benefits. The study was prepared using a variety of national and international sources, which are listed in the selected bibliography at the end of the study.

5. The following summary of the study appears in all the official languages of the United Nations. The full study, contained in the annex to the present document, is being distributed only in the language in which it was prepared (English) because of its technical character.

SUMMARY OF THE STUDY

6. Remote sensing is a highly cost-effective technology for planning and managing natural resources, including land and water resources. Remote sensing data from a variety of satellites are now available to all countries, and a variety of data processing techniques and applications methods have been developed for using those data for various resource management purposes. Satellite remote sensing is particularly valuable for repetitive coverage of large areas, for which aerial or ground surveys may be prohibitively slow and expensive. Remote sensing is still under development, and new satellites with new sensors and new data processing and applications techniques are being developed.

7. Satellite remote sensing is used primarily for mapping the nature and the extent of natural resources. Features that are readily visible on remote sensing images include rivers and streams, bodies of water, forests, grasslands, cultivated fields and cities. These features and the shading and texture of the image can further be interpreted in terms of the landforms and topography of the terrain. From these surface features, deductions can be made about the underlying soils, geology and groundwater.

8. Satellite remote sensing cannot provide all of the information required for the management of land and water resources. Some of the required information is too small in size to be visible on satellite images, and some necessary information, such as administrative boundaries, communication lines and land use regulations, may not be visible on the terrain at all. Aircraft and ground surveys are therefore used to verify and calibrate the interpretations of the satellite data and to collect more detailed information on areas of particular interest. Information from other sources such as existing maps, previous studies and administrative records are also integrated with the satellite observations as necessary for the particular application.

9. A common approach to resource management is to prepare a detailed base map and resource inventory of the area in question and then to monitor the changes from the baseline conditions. The detailed inventory will often make more extensive use of detailed aircraft and ground surveys, while the monitoring of changes can rely more heavily on the repetitive and consistent nature of satellite coverage. The baseline mapping can emphasize the

unchanging elements such as geology, groundwater and soils, which in most areas have already been mapped. Further information on those features can often be obtained from existing aerial photography, even if it is many years old. Satellite remote sensing data can then be used primarily for the more dynamic features such as land use, urban development, forest clearing, cropping patterns and water levels in lakes and reservoirs.

10. For the most rapidly changing features, such as crop and rangeland conditions through the growing season, remote sensing satellites may not offer sufficiently frequent coverage. Where low-resolution data can be used, meteorological satellite images, acquired on a daily basis, can be used for very cost-effective monitoring of resources. For semi-arid regions, a technique has been developed allowing a quantitative estimate of vegetative biomass for use in rangeland monitoring and management, for general crop yield predictions and for early warning of crop failures.

11. Some essential information for land and water resources management, such as water levels in streams, can only be obtained from ground observations. One method for collecting such data in a cost-effective way is through the use of automatic data collection platforms which transmit data via satellite to a central receiving centre for processing and distribution. Such data collection systems are carried on a number of meteorological satellites and are available for use on a worldwide basis.

12. The integration of an increasing amount of data and information from an increasing variety of sources poses major practical problems in information handling. Computer-based geographic information systems are now being developed and applied to assist in integrating resource information from remote sensing and other sources. These systems are programed with a map grid in relation to which resource data and other geographic information can be stored, recalled and processed. Resource managers and planners can use the systems to generate custom maps and statistics responding to specific information requirements as they arise.

13. Remote sensing has proved useful for groundwater development in developing countries. In India, satellite remote sensing has been used in conjunction with aerial and ground surveys to assess the groundwater yield potential of different areas, with the result that the success rate in well boring has increased from about 45 per cent to 90 per cent. The programme uses both photo-interpretation and computer analysis of remote sensing images to derive information on drainage, topography, geomorphology, rock types, geological structure, soils and vegetation. It was found that satellite images are not only more cost-effective than aerial or ground surveys, but they reveal certain large-scale subtle hydrogeological structures that are not visible to a ground observer. The information derived from remote sensing was used to compile maps of groundwater yield potential for the entire country at a scale of 1:250,000. For areas in which existing water supplies were particularly inadequate, more detailed studies were carried out and maps prepared at a scale of 1:50,000.

14. Satellite remote sensing can be used effectively in developing countries to plan the construction of reservoirs and to monitor their use. In Burkina Faso, satellite data were used to prepare an inventory of small reservoirs throughout the country and to identify sites for the construction of additional small reservoirs to provide water during the dry season. Satellite data from different seasons and different years were used to monitor the changes in water levels and to identify the construction of new reservoirs and the deterioration of old reservoirs.

15. In mountainous areas, forests play a vital role in regulating the water supply. Deforestation of steep slopes, either for logging or for agricultural clearing, can greatly reduce infiltration and increase runoff and erosion, reducing the productivity of the land. The increased runoff can also lead to flooding further down in the watershed, and the high sediment loads in the runoff can lead to the sedimentation of reservoirs and channels downstream. Satellite data have also been used to study deforestation in the Amazonia region of Brazil, where it has led to soil degradation and erosion.

16. Remote sensing can play an important role in flood prediction and mapping and in flood protection and relief. Remote sensing and meteorological satellite data provide information on high snowfall or rainfall in watersheds and on the extent and dynamics of flooding and flood recession. The mapping of flood plains, the modelling of flood behaviour and the planning of permanent flood control measures require information on landforms, soils and land use that can be provided by remote sensing.

17. Biomass estimates from meteorological and remote sensing satellite data have been used in semi-arid areas in Kenya and Senegal, together with aircraft and ground surveys, to study the use of rangeland by pastoralists and to plan range management programmes. Satellite data have revealed the degradation of the vegetation in many areas either due to overgrazing, particularly around water supplies, or due to variations in rainfall. Repetitive satellite data have been used to monitor the changing quantity, quality and distribution of vegetation, and aircraft surveys serve to count the numbers and distribution of cattle, sheep, goats and human habitations. That information provides a basis for assessing the ecological balance in different areas, and for taking measures to encourage sustainable pastoral practices. Continuing satellite and aircraft surveys can then assess the effects of new rangeland programmes and policies.

Notes

1/ Official Records of the General Assembly, Forty-sixth Session, Supplement No. 20 (A/46/20), para. 31.

Annex

THE APPLICATIONS OF SPACE TECHNOLOGY FOR INTEGRATED LAND AND WATER RESOURCES MANAGEMENT FOR RURAL DEVELOPMENT

Study by the Secretariat

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INTRODUCTION

1. The ability to observe the Earth from the vantage point of outer space provides a powerful new tool for managing natural resources and monitoring the environment. Since the launch of the first Landsat remote sensing satellite in 1972, the worldwide availability of detailed satellite pictures of the Earth's surface has led to research and development in many countries on the application of satellite remote sensing data to a variety of resource management needs.

2. Remote sensing data is acquired by both satellites and aircraft with a variety of sensors including photographic cameras, electronic multispectral scanners, thermal infrared scanners and imaging radar systems. The applications of remote sensing to land and water resources management for rural development involves all of those techniques along with ground surveys and the use of existing maps, statistics and other information. Each of the techniques has its advantages and disadvantages, and the optimum combination of techniques depends on the specific conditions of each resource management programme and location.

3. While remote sensing satellites provide detailed images of the Earth for the study of natural resources, meteorological satellites produce less detailed but more frequent pictures of larger areas of the Earth, primarily for the purpose of weather forecasting. Meteorological satellite data, particularly when interpreted to estimate rainfall, can provide important information for land and water resources management. In addition, meteorological satellite images of cloud-free areas can be used for large-area surveys of vegetation condition for such applications as rangeland management and crop condition assessment.

4. The present study focuses on the use of remote sensing satellite data for land and water resources management, and examines how aircraft data, ground surveys and meteorological satellite data can complement remote sensing satellite data. Among the different types of satellite data, the emphasis of the study is on multispectral scanner data, since they are the most widely available and the most extensively used. Most of the work on which the study is based has used data from either the United States Landsat System or the French SPOT system, both of which carry multispectral scanners as their primary sensors. Other types of remote sensing systems, including radar and thermal infrared scanners, will also be considered briefly.

5. The immense volume of land and water resources information produced by remote sensing and meteorological satellites not only offers solutions to problems, but can itself be a problem. Users are confronted with a growing number and variety of satellites, sensors, data formats, data processing equipment and data interpretation techniques. Obtaining the required information for a particular purpose often requires combining data from a variety of sources. The study will therefore examine some of the problems of acquiring data and integrating data from different sources.

6. Most of the research and development work in the applications of space technology to land and water resources management has been done in the developed countries. A significant and increasing amount of work in the field, however, is being done in developing countries. While most of the work has focused on commercial land and water development, some work has been done on small-scale and local applications to village and rural life. The present study reviews the applications of space technology to land and water resources management generally, but focuses on applications to rural development in developing countries wherever possible.

7. The purpose of the present study is to provide an overview of these various aspects of the applications of space technology for land and water resources development, considering the various sources of data, the interpretation techniques and the practical applications. The study focuses on the needs of developing countries, and is intended particularly for those organizations that do not have experience in the use of space technology but are interested in the benefits it has to offer.

I. SPACE TECHNOLOGY FOR LAND AND WATER MANAGEMENT

8. Remote sensing satellites such as the United States Landsat series and the French SPOT series provide detailed images of the ground on a worldwide repetitive basis. In low-Earth orbits, Landsat and SPOT satellites pass over every country in the world, collecting data by means of electronic multispectral scanners and transmitting the data to the ground for processing and distribution.

9. While multispectral scanner data is often distributed in the form of images that look very much like photographs, the acquisition of the image by the scanner is quite different from the photographic process. The sensor scans the ground line-by-line as the satellite goes overhead, electronically measuring the light from a series of small areas on the ground along each line. After measuring the light from a few thousand points in one line, the scanner repeats the process for the next line, repeating the process many times per second continuously as long as the sensor is turned on. The brightness of the light from each area on the ground is converted into a number, and a continuous series of those numbers is transmitted to the ground by radio. On the ground, the series of numbers can be received, recorded, processed by computer, and recorded on paper or film point-by-point and line-by-line to reconstruct a photograph-like image of the scene observed by the satellite. Remote sensing applications do not necessarily involve the production of images, since computers may process the data to produce statistics or line drawings or other forms of information, but most applications involve physical images at some point in the process.

10. The acquisition and transmission of a multispectral scanner image as a series of numbers makes it easily adaptable for digital data processing and computer analysis. In fact, multispectral scanner images normally require computer processing and correction before they are suitable for interpretation. Routine data processing usually includes procedures to balance

the sensitivities of different detectors in the scanner, to correct the geometry of the image for the motion of the satellite, and to optimize the contrast of the image.

11. Further data processing can optimize the image for a particular application. For example, for a study of water, the subtle differences in brightness between different parts of a water body may need to be enhanced at the expense of differences in brightness in other parts of the image. Other image processing techniques can be used to enhance boundaries and linear features.

12. Multispectral scanners produce images in a number of spectral bands or colours. The first Landsat Multispectral Scanner (MSS), for example, had four bands, corresponding to green light (0.5-0.6 μm), red light (0.6-0.7 μm), and two bands of near-infrared radiation (0.7-0.8 μm and 0.8-1.1 μm). Since these do not correspond to the primary colours of human vision (blue, green, red), MSS data cannot be used to generate a normal colour picture of the scene. Since interpretation is facilitated through the use of three-colour images, the most common practice is to print or display the green band using blue light, the red band using green light, and one of the infrared bands using red light, producing a "infrared false colour" image. The most striking difference between false colour and normal colour images is that green vegetation appears bright red in the false colour image due to its high reflection of infrared radiation.

13. For particular applications, other colour combinations or black and white images are sometimes used. For example, for delineating water bodies, a black-and-white image of a single infrared band may be effective, simple and inexpensive, since water appears uniformly black in infrared, while vegetation, soils and rocks appear as various shades of medium to light gray.

14. Satellite images can be produced as paper prints, positive film transparencies or negative film transparencies. Interpretation of the image and the use of the interpretation in compiling or annotating a map is facilitated if the image is produced at the same scale as available maps. While some imagery is produced at 1:1,000,000 scale and 1:500,000 scale, for which maps exist for many areas, the most common working scale for satellite image interpretation is probably 1:250,000 or 1:200,000, which are standard map sizes.

15. The optimum scale for interpretation and mapping will depend on the application and on the resolution of the sensor. In general terms, the resolution of a sensor is the smallest object on the ground that is visible on the image. The Landsat Multispectral Scanner has a resolution of 80 m, and its images show fields and lakes of several hectares or larger, major highways and rivers, and the general structure of cities. The current Landsat satellites also carry the Thematic Mapper sensor with seven spectral bands and 30 m resolution. The SPOT satellites carry the HRV (High Resolution Visible) multispectral scanner with 3 spectral bands and either 20 m resolution for false colour images or 10 m resolution for panchromatic black-and-white images. The 10 m to 30 m resolution of current multispectral scanner images

reveals fields and water bodies of under one hectare, rivers and large streams, most roads including city streets, and detailed urban structure. These images can be used effectively for mapping at scales of 1:100,000 and 1: 50,000.

16. While a satellite image is in itself a form of map, an information product for resource management will usually at least add a reference grid, identify such features as cities, lakes, rivers and administrative boundaries, and classify the resources of interest, such as agricultural land, crops, forests, soil types or geological structures. In some cases the map may include colours or shading taken directly from the image, but in most cases the final product will be a line map showing the boundaries of the various features of interest with some schematic colouring, shading or coding to identify each feature. Alternatively, the output of an analysis may be statistical information, such as the acreage of farmland in a given area or the change in the area covered by water.

17. A limitation of most satellite remote sensing data is the lack of stereo coverage, so that quantitative topographic information cannot be extracted. In such cases, the interpretation may be done with reference to existing topographic maps, and the information acquired can be compiled onto topographic maps. Qualitative information on topography can also be obtained from shadows, from drainage patterns, from water surfaces and from other patterns that are determined or influenced by topography. The SPOT satellite, however, has a steerable mirror system enabling the sensor to observe the ground from different angles, thereby providing a capability for stereo imagery. The steerability also enables the sensor to observe an area of particular interest more often and to select cloud-free areas in regions covered by scattered clouds.

18. A major advantage of satellites over aircraft and ground surveys is their ability to cover large areas and to cover areas repeatedly. The orbits used by remote sensing and meteorological satellite are designed to repeat ground coverage at fixed intervals, 16 days in the case of Landsat and 26 days in the case of SPOT, while meteorological satellites provide daily or more frequent coverage. The inherent ability of satellites to provide repetitive coverage makes them ideal for monitoring changing phenomena, including surface water features and vegetation conditions.

19. More detailed images of specific areas can be obtained from aircraft, which most commonly use photographic cameras to acquire the images. In addition to providing very high resolution, aerial photography offers precise geometry and stereo imagery for topographic analysis. While aerial photography often uses panchromatic black-and-white film or normal colour film, colour infrared film can also be used, and combinations of films and filters can be used to produce other colour combinations for special purposes. Aerial photographic analysis has been used for many decades for mapping, and a wide variety of equipment and procedures are available for interpreting the photographs and compiling the information into maps. Photographic systems, however, are limited to the visible and near infrared regions of the spectrum and cannot be used for thermal observations.

20. Visual interpretation of satellite imagery is an extension of air photography interpretation. However, because of the large areas covered by a satellite image and the relatively low resolution, the ground features that appear on the image may not correspond with the objects of our everyday experience such as trees, buildings, roads and streams. The interpreter must be able to recognize larger patterns and to deduce smaller features from their effect on larger features. A small stream for example may not appear as a dark water surface, but as a curving line of vegetation that differs from the surrounding vegetation. A small town may not appear as identifiable buildings and streets, but as a grey, fine-textured patch which is distinct from the colour and texture of the surrounding fields and woods. Settlements are also often indicated by intersecting roads and are commonly located on rivers, streams or bodies of water.

21. While the lack of detail in satellite imagery is often a disadvantage for resource interpretation, it can also be an advantage. An agricultural field, for example, will not appear on a satellite image as an array of plants on plowed soil with periodic tractor tracks, but as a more homogeneous average of plants and soil. The average colour of an agricultural crop in a given region may be more characteristic of the crop that is the colour of the individual plants. Similarly, in a forested area, the satellite sensor will not see individual trees, but the average appearance of that particular mixture of tree species and undergrowth. In general, however, the major advantage of satellite remote sensing over aerial photography or remote sensing is the lower cost of repetitive coverage of large areas.

22. Where features on the order of a metre or less in size need to be observed, aerial photography can be used to complement the lower-resolution information from satellite data. Ground surveys may also be necessary for such purposes as identifying vegetation species in natural pasture, analyzing water quality and determining human population density. A complete and accurate resource management programme will therefore often require a combination of satellite imagery, aerial photography and ground survey information, used together with existing maps and other information.

23. In general, the cost of acquiring, processing and interpreting data increases with the amount of detail in the data. Thus for covering a given area, satellite coverage would be the least expensive, followed by aerial photography, with ground surveys as the most expensive data-gathering technique. A cost-effective information system might therefore obtain as much information as possible from satellite data, use limited aerial photography, perhaps on a sampling basis, to provide details not obtainable from the satellite data, and use occasional ground surveys for checking the satellite and aerial image interpretation and gathering the remaining required data. For programmes involving continuous monitoring, aerial and ground surveys may be needed to establish the baseline conditions, with repetitive satellite data used for the ongoing monitoring.

24. While the Landsat and SPOT satellites pass over all areas of the world on a regular basis, the availability of data depends on facilities for receiving and processing the data

transmitted by the satellite. The satellites transmit the data as they are acquired to any ground station within view of the satellite, which means that a ground station can receive data for an area about 2500 km in radius around the station. Data for areas not covered by a ground station can be recorded on board the satellite for later transmission or can be transmitted via a relay satellite to a central receiving station. However, due to limited on-board recording capabilities and the limited availability of relay satellite capacity, areas not covered by ground stations generally have significantly less data available than areas that are covered. Currently some 18 countries covering most of the world operate stations for receiving data from Landsat and SPOT satellites, but most of Africa is not covered by any of those stations. The lack of a local receiving station particularly limits applications that require frequent coverage and rapid availability of data, such as environmental monitoring.

25. The acquisition of useful data by Landsat and SPOT is also limited by cloud cover. For most parts of the world this reduces coverage from once every few weeks to perhaps once per season. In some tropical areas, however, persistent cloud cover may make any useful data acquisition very difficult. In other areas, cloud cover may be seasonal, limiting coverage to the dry season, a condition which poses little problem for geological and soil surveys, but limits the acquisition of agricultural information during the growing season.

26. The problem of persistent cloud cover can be overcome through the use of radar, which can acquire images day or night and through clouds. Airborne radar has been used for many years, both in the humid tropics and in other areas. Satellite radar systems have been used experimentally in the past and have provided data that has been interesting, but too limited in quantity to allow many practical applications. That situation should now change following the 1991 launches of the European Space Agency's ERS-1 (Earth Resources Satellite) and the Union of Soviet Socialist Republics' Almaz satellite, both carrying imaging radar systems as their principle sensors. Radar data can be processed into images that appear rather like black-and-white photographs, but require some special considerations for their interpretation. Since the radar signals emitted by the sensor illuminate the terrain at a low angle, hilly ground will show strong shadowing effects similar to those produced by a low sun on photographs or multispectral imagery. Furthermore, radar can penetrate vegetation, revealing the land surface underneath. Radar images are therefore particularly useful for studying rough terrain, drainage patterns, geomorphology and geological structure. Water surfaces generally appear uniformly black on radar imagery, providing a strong contrast between bodies of water and other surfaces. The reflection of radar signals from soil depends on the moisture content of the soil, so radar can be used for monitoring soil moisture content, but the interpretation of images for this purpose can be difficult.

27. Resource management, particularly in such broad areas as land and water resources management, requires the integration of remote sensing data with information from a variety of other sources. Handling the volume of data required and combining the different types of information can pose difficult practical problems. Furthermore, there is often no single optimum way to integrate the information from different sources and no single ideal map

product that can meet the needs of different resource managers and planners. An important technique for integrating information from various sources in a flexible and interactive way is the computer-based geographical information system (GIS). The computer is programmed with a map base onto which geographic information from remote sensing systems or other sources can be entered. Historical data can be combined with current data to indicate trends and make future projections. The user can then combine the different information in various ways to provide answers to various management questions. An agricultural planning project, for example, might need to take into account information on soils, rainfall amount and seasonal distribution, topography, availability of irrigation water, existing land use, population density, administrative boundaries, and transportation and communication facilities. Information on these elements could be combined according to an agricultural economic model to produce a map of recommended land use for planning purposes. While GIS systems are complex and expensive to establish, once established they can quickly and inexpensively produce maps with land classified according to complex criteria specifically determined for the project in question.

28. In addition to providing imagery, satellites are also used to relay data from ground data collection platforms to a central receiving and processing station. Such satellite data collection systems (DCS) are particularly useful for frequently and efficiently collecting data on hydrological and meteorological parameters such as streamflow, rainfall, snow cover, and air and water temperature. After collection and processing at a central facility, the data can be quickly distributed to users via another relay system on the same satellite. Data collection platforms may transmit their data at fixed time intervals, when interrogated by the satellite, or when a specified alert condition occurs. Satellite data collection systems are particularly useful for real-time collection of data from mountainous or remote areas with limited facilities for transportation and communication.

29. While the first satellite data collection system was carried on the early Landsat satellites, data collection services are now provided by a number of meteorological satellites launched by different countries and organizations. One system is the French Argos Data Collection and Location System carried on the United States polar-orbiting NOAA satellites. The Argos system, in addition to relaying data from automatic platforms, can also track moving platforms such as oceanographic buoys carried by ocean currents. A number of geostationary meteorological satellites including the United States GOES (Geostationary Operational Environmental Satellites), the European Meteosats, and the Japanese GMS (Geostationary Meteorological Satellites) also carry data collection systems.

30. As noted above, the main function of both polar-orbiting and meteorological satellites is to transmit cloud images, showing the distribution of the clouds and the temperature of the top surface. In cloud-free areas, of course, the images are of the ground. For environmental studies of very large areas for such applications as drought monitoring, crop condition assessment or snow cover mapping, meteorological satellite data may be useful. The disadvantage of the low resolution (1 to 4 km) may be acceptable for large area averages, and

the availability of daily coverage may be crucial to some applications. Another major advantage of meteorological satellite data is its low cost, particularly if calculated as cost per unit area.

II. WATER RESOURCES MANAGEMENT AND DEVELOPMENT

A. Principles of water resources management

31. In general, the purpose of water resources development and management is to ensure a supply of water of sufficient quality and quantity to meet the demands of a population, both in the present and for the foreseeable future. Most commonly, a steady increase in water supply is required to meet a steadily increasing demand arising from population growth and agricultural and industrial development. Water resources development and management usually involves the elaboration of a water budget that balances consumption with the supply from various sources.

32. The largest demand for water generally is for agricultural irrigation, followed by demand for human and animal use, and then by industrial use. The use of water for a particular purpose may reduce the supply for other purposes or may return the water to the source for further use. Water used for irrigation or for human needs, for example, is water that is either lost or requires treatment to restore its quality. Some irrigation water may be recovered through drainage systems, but the salt and other chemicals that are picked up by the water as it permeates the soil makes it unsuitable for many uses. Similarly, many industrial uses of water leave it unfit for other uses, at least until it has been treated. On the other hand, the use of water to generate hydroelectricity does not reduce the supply for other purposes. The course of a river might be altered for the reservoir and hydroelectric dam, but all of the water can be tapped again downstream for other uses.

33. The distribution of natural water supplies over an area generally does not conform to the distribution of demand. Natural water supply also varies in time in ways that do not match demand. Effective water management therefore requires reservoirs, canals and pipelines to make water available when and where it is needed. These structures, of course, do not increase the total amount of water, but merely redistribute it in time and place. In fact, reservoirs cause some loss of water by providing a larger surface area for evaporation. In redistributing water over time, from seasons of excess supply to seasons of excess demand, reservoirs not only help to meet the demand, but can also play an important role in flood control.

34. While space technology cannot increase the supply of natural water, it can make water supply planning and management more efficient and effective. Both satellite remote sensing systems and satellite data collection systems can provide valuable inputs to these processes in a timely and cost-efficient manner. Remote sensing can provide a synoptic view of complete watersheds, assist in quantifying and monitoring available surface water, and provide limited

information on the quality of the water, particularly regarding its temperature and suspended solid particle concentration. Remote sensing can also be used in the siting and construction of reservoirs, for locating favourable areas for groundwater development, and for planning agricultural development to make most efficient use of available irrigation water. A network of data collection platforms can also provide important information for water resource planning and monitoring, including warnings when the water levels in rivers or reservoirs exceed safe limits so that public safety measures may be taken.

B. Mapping the hydrological network

35. A basic starting point for the management of water resources in an area is the preparation of a detailed drainage map of the area. While a detailed drainage map can generally best be compiled from aerial photography, using the topographic information from stereoscopic analysis, satellite images can also be used. The drainage system that develops on a regional surface is controlled by the slope of the surface, the type of soil, and the nature and orientation of the underlying rocks. Drainage patterns therefore reflect the geological structure and history of a region and provide useful information not only for water resource management, but also for land use planning and geological exploration.

36. Satellite imagery and aerial photography reveal the orientations and density of the drainage network which can be interpreted in terms of the underlying structures. A drainage network in which the major tributaries are parallel to each other and join the mainstream at approximately the same angle, for example, indicates a homogeneous, gently and uniformly sloping surface whose mainstream may follow a fault or a fracture zone. Such parallel networks are usually found on young coastal plains and large basaltic flows. A high density of drainage lines would be indicative of impervious bedrock or clay soils of low permeability. At the other extreme, a watershed with few drainage lines would probably be underlain by permeable bedrock materials and coarse, permeable soil materials.

37. Small streams and gullies have shapes that are characteristic of the eroded materials. When observable on high-resolution images, these characteristics provide information on the nature and texture of the soil. Where bare soil is visible, its tone on the images is an important factor for interpretation. Lighter tones generally indicate coarse and well-drained soils low in organic matter, while dark tones are associated with fine and poorly-drained soils usually rich in organic matter.

38. A map of the drainage network, together with information on rainfall and streamflow, perhaps collected through a satellite data collection system, indicates the sources of water and their geographic and seasonal distribution. A comparison of that information with information on the demand for water and its geographical and seasonal distribution indicates the requirements for the water resources management system. Of the water that falls on the land, some will be lost to evaporation, some will infiltrate the ground to become groundwater, and some will remain on the surface as runoff into streams, rivers and lakes. When the

surface water is adequate to the demand, redistributed through reservoirs and canals as necessary, it is normally the simplest and least expensive source. When surface water is not adequate, then groundwater can be tapped.

C. Surface water mapping and monitoring

39. Mapping and inventorying surface water is one of the simpler remote sensing applications. Water is relatively transparent in the visible part of the spectrum, with maximum transparency for blue-green light, but absorbs an increasing amount of red light and infrared radiation. The combined use of different wavelengths therefore allows reliable discrimination of water from other features and provides information on both surface and subsurface phenomena down to some depth. Among the features that can be identified on remote sensing imagery are the location and extent of surface water bodies, the location of inflow and outflow to and from a water body, current patterns within the body, sediment transport, and surface and underwater vegetation. Water depth can often be estimated in shallow water, and water quality can be studied through observations of suspended sediment, temperature and vegetation. Chemical pollutants, however, generally cannot be directly observed.

40. Since water absorbs quite strongly in the near-infrared, while vegetation and soil are relatively reflective, infrared bands provide the clearest distinction between water and land, even for very shallow water. Water that is covered by vegetation, however, may be difficult to interpret due to the strong infrared reflectance of the vegetation. Green spectral bands, providing the deepest penetration of the water, are best for observing sedimentation patterns and bottom features, down to depths as great as 15 m under very clear water conditions.

41. Water temperature can be measured from satellites or aircraft using electronic scanners operating in the 8 to 14 µm thermal infrared band. Objects at normal environmental temperatures have maximum thermal radiation in this band, which is also a band of low atmospheric absorption. While thermal images often look like black-and-white photographs, temperature is a much more dynamic feature than reflectance, and the interpretation of thermal imagery must take into account the thermal properties of water. On a sunny day, for example, a land surface will warm up quickly while a nearby lake or river will warm up more slowly, so that by afternoon the land may be substantially warmer than the water. At night, the land cools off quickly, leaving the water relatively warm. In either case, land and water will appear quite distinct on thermal imagery. In the morning and evening, on the other hand, the water surface may have the same temperature as the surrounding land and will have the same brightness on thermal imagery. Thermal imagery can be used for observing the temperature differences over the surface of a water body, allowing the study of water currents, thermal pollution from heat sources, and the location of natural sources of hotter or colder water.

42. Natural and artificial bodies of water are important for water storage to redistribute water supplies between seasons of excess rainfall and seasons of excess consumption. Water levels in lakes, rivers and reservoirs will generally be lowest at the beginning of the rainy season or snowmelt period and highest at its end, and an adequate supply of water through the dry season will depend on adequate accumulation during the rainy season. Regular monitoring of the water levels through the seasonal cycles is an essential part of water management. While the monitoring of water levels in large reservoirs near populated areas is generally routine without remote sensing, the monitoring of small reservoirs scattered through rural areas may be a useful application of remote sensing. Since the area covered by a lake or reservoir expands as water level rises, the monitoring of surface area on satellite imagery can be readily calibrated in terms of water level and water volume. The repetitive monitoring of the surface area from season to season can indicate the adequacy of the supply for existing or prospective needs.

43. Satellite remote sensing can be used effectively in developing countries to plan the construction of reservoirs and to monitor their use. In Burkina Faso, satellite data were used to prepare an inventory of small reservoirs throughout the country and to identify sites for the construction of additional small reservoirs to provide water to nearby villages during the dry season. Satellite data from different seasons and different years were used to monitor the changes in water levels and to identify the construction of new reservoirs and the deterioration of old reservoirs. Satellite data has also been used for planning and managing the use of stored water for agricultural irrigation to ensure that the best use is made of the very limited supplies.

D. Groundwater development

44. In general, there is a much greater volume of fresh water underground than on the surface, and remote sensing can be used to develop and manage groundwater resources. Groundwater, like surface water, is a renewable resource and in the long term can only be consumed at the rate at which it is replenished. The development and management of groundwater resources therefore requires the location of groundwater resources, the assessment of sustainable exploitation rates, and planning and management to insure that exploitation does not exceed replenishment.

45. While the drainage network and surface water can be seen directly on remote sensing images, groundwater cannot. Its presence must therefore be deduced from the surface features through the use of hydrogeological theory. Groundwater is found in the interstices and voids within rocks, and is available for extraction if the interstices and voids are large and continuous enough to allow water to flow and accumulate. Remote sensing for groundwater exploration cannot definitively identify sources of groundwater, but can indicate areas where the presence of groundwater is most promising and where ground and geophysical surveys should be most cost-effective.

46. In arid regions, outcroppings of bedrock may be directly observable on remote sensing images, which can then be interpreted in terms of rock types, bedding, fracturation and the relationships among different geological units. In most areas, however, the bedrock is covered by vegetation and soil that prevent direct observation. Hydrogeological interpretation must then be based on the surface effects of the underlying geological structures. As indicated above, the drainage network is generally the clearest indicator of the underlying geology.

47. Vegetation patterns are also useful to water resources exploration. In areas of natural vegetation, the type and density of vegetation depend in part on the soil type, which is derived from the underlying rock. Distinctive vegetation patterns or the presence of vegetation in otherwise bare areas may indicate fractures or areas of permeable soil and rock in an otherwise impermeable area. Vegetation can also indicate areas of shallow water table, and rows of shrubs or trees in arid areas may reveal the path of water flowing underground. Vegetation mapping can be useful in assessing groundwater recharge since vegetation retains rain water and reduces runoff and therefore favours infiltration of water into the soil and the recharge of aquifers in the substratum.

48. In cultivated areas, crop fields displaying regular patterns usually indicate alluvial plains and terraces where thick soil of good quality is present. In such cases, the density and type of crop can be related to variations in soil moisture. Irregular patterns of crop density are indicative of uneven terrain and variations in soil type and thickness.

49. False colour images using a near-infrared band are generally the best form of satellite data for interpreting vegetation cover due to the high reflectance of vegetation in the infrared and its sensitivity to environmental conditions. In the case of imagery from the Landsat Thematic Mapper, the use of band 5 (1.57-1.78 μm) can add additional elements of discrimination in areas of natural or agricultural vegetation as it is sensitive to soil and moisture conditions.

50. An important technique in remote sensing applications to groundwater development is lineament analysis, using all of the linear features observable on an image. Linear features on the image reflect a variety of ground phenomena, including ridges, valleys, drainage channels, rows of springs or ponds, elongated areas of distinctive soil or rocks. They appear on images as lines or boundaries between different tones, colours or textures. When the linear features are tens or hundreds of kilometers long they are called lineaments and are interpreted as reflecting large subsurface tectonic structures including fractures where groundwater can collect and flow. In areas of carbonate rocks, the fracture zones may form extensive networks of groundwater conduits, while in crystalline rocks, fracture zones and fracture crossing points are generally the only sites where groundwater is likely to occur.

51. Lineaments are best observed in the near infrared bands because low atmospheric scattering enhances the shadowing effect of ridges and valleys. The combination of red and

infrared bands is particularly useful when the presence of moisture along lineaments results in lines of denser vegetation in otherwise sparsely covered areas. Suitable scales for lineament analysis on satellite imagery are 1:250,000 and 1:200,000, although the resolution of the new generation of satellites permits this analysis to be done up at scales up to 1:50,000.

52. A groundwater exploration programme would generally use all of the interpretation techniques described above, together with the analysis of information from other sources. The first step might be the use of satellite data to determine the drainage network and vegetation distribution and to deduce information on soils, rocks and geological structures. The information derived from remote sensing would then be correlated with other available information and maps of the area, including in particular geological maps or studies. Areas that appear to be favourable for ground water exploration might then be studied in more detail by aerial surveys, with ground surveys of specific sites to check the interpretations of the satellite and aerial data. Finally, all of the information would be compiled into specific thematic maps, including morphology, geology, drainage, land cover and lineaments, and into a general hydrogeological map indicating the most likely sites for groundwater development.

53. Remote sensing has proven useful for rural groundwater development in developing countries. In India, data from Landsat, SPOT and the Indian IRS remote sensing satellite have been used in conjunction with aerial and ground surveys to identify the groundwater yield potential, with the result that the success rate in well-boring has increased from 45 per cent to 90 per cent and the cost has been substantially reduced. The programme uses both photointerpretation and computer analysis of remote sensing images to derive information on drainage, topography, geomorphology, rock types, geological structure, soils and vegetation. It was found that satellite images are not only more cost-effective than aerial or ground surveys, but that they also reveal certain subtle large-scale hydrogeological structures that are not visible to a ground observer. The information derived from remote sensing was used to compile maps of groundwater yield potential for the entire country at a scale of 1:250,000. For areas in which existing water supplies were particularly inadequate, more detailed studies were carried out and maps prepared at a scale of 1:50,000. Remote sensing has also been used in the planning of structures for conserving runoff and increasing the recharge of groundwater sources.

III. LAND USE AND ENVIRONMENTAL MANAGEMENT

A. Watershed management

54. Water resource planning and management is usually done on the basis of the watershed area of a particular river, since any use or storage of water in any part of the watershed will affect all downstream areas. Similarly, land use throughout the watershed will affect the runoff of rainfall and snowmelt and affect downstream areas. Watershed management is therefore a complex process involving information on a variety of natural phenomena and human activities and requiring the regulation of human activities to ensure a safe and

adequate water supply for various purposes. Management actions may take the form of agricultural and land use planning, construction and operation of reservoirs, road and building construction, irrigation projects, livestock husbandry and forest management. Remote sensing can contribute information for use in all of these activities.

55. As in other applications, remote sensing data often needs to be interpreted in conjunction with information from other sources, particularly for quantitative measurement of hydrological processes. For instance, it is not possible to determine erosion in tons per hectare or runoff in cubic metres per second from remote sensing data alone. To estimate erosion, for example, data would be needed on soils, slopes, vegetation, rainfall and cultivation practices in a watershed. From these elements, a model of the behaviour of the watershed in response to different rainfall patterns could be developed, and ground measurements could be used to verify and calibrate the model. Once the model was established, its routine use could be based largely on input from remote sensing and meteorological satellites and automatic ground stations, with a minimum of new ground survey inputs.

56. That approach, of collecting detailed baseline data on conditions at a particular time, constructing a model of the dynamic behaviour of a natural system, and then monitoring changing conditions by means of satellite observations, has proven cost-effective for many applications. The repetitive coverage patterns provided by the Landsat and SPOT satellites facilitate change monitoring since images acquired in different years or seasons are consistent with respect to time-of-day, scale and ground coverage. Two images from different dates can therefore easily be compared to determine changes. The digital nature of the data transmitted by the satellites facilitates computer processing for image comparison and automatic or semi-automatic preparation of maps showing changes. A simple example of change detection might be the monitoring of snow cover over a watershed, generally a fairly simple procedure since snow is usually easily distinguishable from bare ground. The extent of snow cover in the winter and the gradual decrease in the area of snow cover in the spring can be related to the volume of runoff and can be used to manage reservoirs. Changes due to deforestation, increasing cultivation, and urban expansion can also have important effects on the management of water resources and can be followed on satellite imagery.

57. An example of a watershed management technique using remote sensing is that of runoff estimation. The United States Conservation Service has developed a Runoff Curve Number Method by which daily rainfall data are converted into stream discharge estimates in small catchments. Inputs to the model include information on soils and vegetation, both of which can be mapped using satellite images. The soil and vegetation information is used to determine what sort of mathematical curve represents the response of the catchment to runoff, and the appropriate curve is then used to estimate the runoff from the measured rainfall. For determining the soils information, the boundaries of soil types can be determined from remote sensing imagery, and the specific soil types can be identified from field sampling. Similarly, areas of homogeneous vegetation can be delimited on the imagery, and field sampling of each area can determine the species composition and nature of the undergrowth and litter, which

affects the runoff characteristics. Eucalyptus forests, for example, which are attractive because of their rapid growth and hardiness, are poor forests from a hydrological perspective and often suffer from high erosion. Young secondary forests, while they have a lower commercial value, are effective in slowing runoff and preventing erosion.

58. An important aspect of watershed management is flood control. Remote sensing can play an important role in flood prediction and mapping and in flood protection and relief. Remote sensing and meteorological satellite data provide information on high snowfall or rainfall in watersheds that can lead to flooding downstream. The mapping of flood plains and the planning of permanent flood control measures require information on geomorphology, soils, land use and vegetation cover in order to ensure that flood control structures are adequate for the largest expected floods, without being unnecessarily expensive.

59. A major concern in many developing countries relating to flood control and water management is the clearing of slopes in the upper regions of watersheds leading to substantially increased volume and rate of runoff during and following rainfall. Remote sensing provides an effective means of monitoring deforestation, the extent of cultivation and the removal of natural vegetation. Increases in the sediment carried by streams and rivers as a result of the increased runoff and decreased vegetation cover can reduce the capacity of reservoirs and accumulate in river beds, thus increasing the risk of flooding.

60. Data obtained at different times during and following a flood can be used not only for immediate flood relief purposes, but also for studying the dynamics of flooding in the watershed for planning future flood control measures. The satellite images clearly show the extent of surface water at different times, and the wet ground from which flood waters have recently receded is also usually identifiable. Satellite data are often a unique source of information during floods, since other sources of information are likely to be disrupted.

B. Land use planning and management

61. For land use planning and management, as for water resources management, a map of the drainage network is often a good first step. The drainage pattern provides information not only on the availability of water, but also on topography, geomorphology, geological structures and soils. On satellite images that do not provide stereoscopic information, the drainage network and the shading due to relief are the best indicators of geomorphology. The drainage pattern indicates the direction and steepness of slopes, while changes in shading indicate changes in slope, and the texture of shading indicates the roughness of the terrain. On the basis of these elements, an image can be divided into such categories as mountainous areas, high plateaus, foothills, alluvial fans, flood plains and coastal plains, which can serve as a basis for land use planning. Differences in tone and colour on an image due to vegetation or soil differences can also be used as indicators of geomorphology, although the significance of particular colours and tones is usually specific to an area, precluding the development of general rules of interpretation.

62. Vegetation mapping is usually done with infrared false colour images, since the infrared reflectance of green plants depends on the particular species and on the environmental conditions. Differences in vegetation therefore tend to show up clearly on the false colour images, and vegetation density and the boundaries between different species or communities can be readily mapped. Information on the soils, topography and climate, combined with information on the vegetation indigenous to the region, can then be used to deduce the actual species present in the area of the image. Ground sampling can be used if necessary to verify and calibrate the remote sensing interpretations.

63. Cultivated fields are generally identifiable by their geometric shapes, their homogeneous colours and their location on relatively flat ground. Different crops generally appear as slightly different colours, and a knowledge of the farming practices of the area may allow reasonably accurate inferences as to the specific crops. In general, however, accurate identification of crops requires ground verification. Nonetheless, remote sensing can greatly increase the efficiency and reduce the costs of agricultural inventories by mapping homogeneous areas which can then be identified in terms of crop species and yield with a minimum of expensive ground surveys.

64. The boundaries between soil types can often be interpreted using the drainage patterns,the geomorphology, the vegetation patterns and other colour and texture differences on the imagery. Geological information, sometimes derived from the forms or colours of nearby mountains, may indicate the rock type from which the soil developed. As with vegetation, accurate identification of the specific soils, however, requires either detailed knowledge of the area or ground sampling. The information on soil types and distribution can then be compiled into soil maps, which are an essential input, along with water resources information, to land use planning and management.

65. The determination of soil moisture conditions, for irrigation management and other agricultural operations, is often difficult from remote sensing data, but under some conditions information can be obtained. In arid or semi-arid regions during dry periods, areas of subsurface moisture will appear as red areas on an image due to the green vegetation they support. In more humid areas, bare or partially bare soil will generally appear dark when the surface is wet, perhaps due to a shallow watertable. The development of satellite radar applications may provide an important tool for monitoring soil moisture. While remote sensing using visible and infrared wavelengths can only observe the surface, radar waves penetrate at least a few centimetres and sometimes a few tens of centimetres into the soil, and the strength of the reflection depends on the moisture content of that surface layer.

66. The general procedure for land use planning and management would make use of information on drainage, geomorphology, natural vegetation, agricultural cultivation, soils, geology and water resources. The first step in the preparation of a map for planning and management purposes might be the preparation of a base map based on interpretation of the drainage network and geomorphology. Onto this base map could be compiled information on

vegetation, soils, land use and geology. Aerial photography and ground surveys could be used to verify and calibrate the remote sensing interpretation and to collect information on features for which the interpretation was uncertain. Information on administrative boundaries and transportation and communication facilities would also be compiled from other sources. Finally, a map corresponding to the specific management requirements of the decision-makers would be prepared, with accompanying analytical and explanatory reports.

C. Environmental monitoring

67. For monitoring the conditions of resources that are sensitive to environmental conditions and that change over periods of days to weeks, such as crop conditions or rangeland carrying capacity, remote sensing data must be available frequently and reliably. Remote sensing satellites such as Landsat and Spot, which provide coverage every few weeks subject to cloud conditions, do not provide sufficiently frequent data to allow such monitoring. Meteorological satellites, however, provide daily coverage, although at lower resolution. Allowing for cloud cover, good images of the ground can often be obtained at about weekly intervals.

68. The most commonly used meteorological system for vegetation monitoring is the Advanced Very High Resolution Radiometer (AVHRR) carried by the United States NOAA satellites. The AVHRR system provides data with 1 km resolution in five spectral bands, one each in the visible, near-infrared and middle-infrared regions of the spectrum, and two bands in the thermal infrared. The difference between the reflectance in the red and near-infrared bands has proved to be a particularly good estimator for green biomass. A standardized quantitative index derived from this difference is the "normalized difference vegetation index" (NDVI), defined as the difference between the infrared and the red bands divided by the sum of the two bands. For sparse vegetation, such as in arid or semi-arid rangeland, the index is often roughly proportional to biomass. For denser vegetation, the index indicates the condition of the vegetation, but without a simple mathematical relationship.

69. Biomass estimates from meteorological and remote sensing satellite data have been used in Kenya and Senegal, together with aircraft and ground surveys, to study the use of rangeland by pastoralists and to plan range management programmes. The sustainable carrying capacity of semi-arid rangelands in those countries is limited by vegetation and water supplies, and overgrazing can result in substantial reduction in the carrying capacity. Repetitive satellite data reveal the degradation of the vegetation in many areas due to overgrazing, particularly around water supplies. In Kenya and Senegal, meteorological and remote sensing satellite data have been used to monitor the changing quantity, quality and distribution of vegetation, while aircraft surveys are used to count the numbers and distribution of cattle, sheep, goats and human habitations. Ground sampling is used to calibrate the satellite data and to collect more information on areas of particular concern. An assessment can then be made of the ecological balance in different areas, and measures can

be taken to encourage sustainable pastoral practices. Continuing satellite and aircraft surveys can assess the effects of rangeland programmes and policies.

70. The response of natural rangeland to varying rainfall and varying intensities and patterns of grazing, and the response of pastoralists to changing conditions, is not yet fully understood. Since the study of those phenomena requires surveys of large areas at regular intervals, satellites may be the only economically feasible means of collecting much of the required data. In fact, even remote sensing satellite data may be prohibitively expensive for regular surveys. Integrated use of regular observations by meteorological satellites, together with selective use of remote sensing satellite data, aircraft data and ground surveys are therefore essential to research in this field in order to provide a basis for effective management.

71. In the ARTEMIS (Africa Real-Time Environmental Monitoring using Imaging Satellites) programme of the United Nations Food and Agriculture Organization, meteorological satellite data are being used for the detection and monitoring of potential desert locust habitats in the arid areas of Africa. Thermal infrared data from the European geostationary Meteosat satellite are used to estimate rainfall based on cloud-top temperatures, taking into account the latitude and the season. Hourly Meteosat cloud observations are integrated over a period of 10 days to estimate the probable rainfall for that period. Visible and near infrared AVHRR data from a NOAA satellite, at a resolution of 4 km and integrated over a month to eliminate clouds, are used to determine the vegetation index over the region. The resulting computer-generated maps of estimated rainfall and vegetation index are sent to the FAO desert locust control programme, where they provide an input into assessments that are sent to Governments and international organizations. The maps are also sent to the FAO Food Early Warning Programme and to a number of regional projects in Africa. These meteorological satellite data products are proving to be effective for pinpointing potential breeding habitats and allowing more rational and efficient field surveys to locate locust outbreaks and plan control operations.

IV. FUTURE PROSPECTS

72. Satellite remote sensing technology and applications techniques using multispectral scanners in the visible and infrared spectral regions are quite well developed and are not likely to change dramatically in the near future. The Landsat and SPOT satellites are expected to continue providing data, as are meteorological satellites. There is, however, great potential for increased applications of remote sensing for integrated land and water resources management for rural development in developing countries. Among the obstacles to increased applications are the lack of people trained in image interpretation, the high cost of data, particularly for repetitive coverage of large areas, and the lack of regular coverage in some areas, particularly in Africa.

73. Applications of satellite radar data to land and water resources management should be developing rapidly in the next few years as the data become widely available for the first

time. In addition to the ERS-1 and Almaz satellites launched in 1991, the Japanese Earth Resources Satellite (JERS) will be launched in 1992, and the Canadian Radarsat is scheduled for launch in 1994. As with other remote sensing satellites, the extent to which the data are used will depend on the availability of trained interpreters and the availability of data at affordable prices.

74. The development of computer-based geographic information systems for integrating data from different sources and producing maps designed for the specific needs of decision-makers should increase the practical benefits that can be achieved through the use of satellite data. Such systems are being developed and commercialized and are becoming more powerful, easier to use and less expensive.

75. With those developments in the 1990s, space technology can be expected to be applied more widely, including applications for integrated land and water resources management, and to make an increasing contribution to the economic and social development of countries throughout the world.

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